Vertical Land Motion at the Ballona Wetlands Ecological Reserve

Site-Specific Relative Sea Level Rise and the Adequacy of rEIR Flood Modeling

Ballona Wetlands Ecological Reserve • Los Angeles, California

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Executive Summary

Vertical land motion (VLM) is a first-order variable in any technically adequate assessment of relative sea level rise (RSLR) at a coastal site. This report presents the scientific basis for requiring site-specific VLM analysis in the revised Environmental Impact Report (rEIR) currently being prepared by the California Department of Fish and Wildlife (CDFW) for the Ballona Wetlands Ecological Reserve (BWER).

The foundational problem is straightforward. Relative sea level rise at any coastal point is the sum of two independent components: the eustatic rise of the ocean itself and the vertical motion of the land surface. If flood modeling uses only regional ocean projections without incorporating local, geodetically measured VLM, it will systematically underestimate relative sea level exposure. In a basin where land is subsiding, this is not a marginal error. At subsidence rates in the range documented for the Los Angeles coastal zone, the accumulated additional flood exposure by 2050 reaches decimeter scale — material to levee freeboard calculations, inundation modeling, and infrastructure risk characterization alike.

Three independent drivers of VLM are present at and immediately adjacent to the BWER site: compaction of Holocene alluvial and estuarine sediments; subsurface pressure cycling associated with the Playa del Rey natural gas storage field operated by SoCalGas since 1955; and historical groundwater extraction from the underlying basin. High-resolution InSAR data from NASA/JPL and NOAA (Sentinel-1, 2015–2023) demonstrates that the Los Angeles coastal zone exhibits spatially heterogeneous and temporally nonlinear VLM that regional averages cannot capture. Peer-reviewed analysis demonstrates that in parts of Los Angeles, failure to account for local VLM can cause flood projections to understate relative sea level rise by more than a factor of two by 2050.

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Two policy consequences follow directly from this technical finding. First, the 68,000 cfs flood design standard mandated by the Chalfant ruling must be evaluated in terms of water surface elevation and freeboard under dynamic VLM conditions, not discharge alone. A levee designed to a fixed discharge standard on the assumption of static ground elevations will not provide equivalent protection in a subsiding basin. Second, the risk characterization of the No Project alternative requires reassessment. Opening additional tidal prism into a basin that is subsiding from multiple overlapping causes could strand infrastructure and habitats sooner than coarse regional projections suggest, making the No Project alternative materially less risky than the prior EIR portrayed. Both conclusions are grounded in the current peer-reviewed literature and are directly relevant to the rEIR process.

1. Conceptual Framework: Relative Sea Level Rise

Relative sea level at any coastal point is determined by two independent variables:

Relative SLR = Eustatic Ocean Rise + Vertical Land Motion

The eustatic component — the rise in ocean height driven by thermal expansion and ice melt — is what regional projections from the California Ocean Protection Council (OPC) quantify. VLM is entirely independent: subsidence adds directly to effective sea level rise; uplift subtracts from it. Where land is sinking, a community experiences the full eustatic rise plus an additional increment equal to the rate of subsidence multiplied by elapsed time.

This distinction is not a minor technical refinement. At subsidence rates of 2–3 mm/yr, a 25-year projection accumulates 50–75 mm of additional effective sea level rise beyond the eustatic component alone. At 5 mm/yr, the additional exposure reaches 125 mm by 2050 — a decimeter-scale effect that materially alters inundation modeling, levee freeboard calculations, and infrastructure risk characterization. At documented Southern California coastal hot spots approaching 8–9 mm/yr, the implications for any project modifying flood control infrastructure are substantial.

High-resolution InSAR measurements have further established that VLM is spatially heterogeneous and temporally nonlinear: neighboring parcels can show meaningfully different rates, and those rates can accelerate or decelerate depending on extraction activity, precipitation cycles, and sediment consolidation state. This spatial patchiness, resolved at scales of tens to hundreds of meters, means that regional averages or sparse GNSS station networks — typically spaced at 20 km or more — are inadequate for site-scale flood risk analysis. The scientific standard has advanced, and the rEIR must reflect it.

2. The InSAR Evidence Base

The current authoritative dataset for California coastal VLM is the Sentinel-1 InSAR analysis conducted jointly by NASA Jet Propulsion Laboratory (JPL) and NOAA, covering 2015–2023 and published in Science Advances (Govorcin et al., 2025). This study provides 90-meter-resolution VLM estimates for the full California coastline and is the scientific foundation for the modeling requirements set out in this report.

The study's key findings for the Los Angeles region are as follows. The coastal zone exhibits high spatial heterogeneity in VLM, with localized subsidence and uplift patches that diverge substantially from regional averages. Subsidence rates in coastal Los Angeles hot spots reach into the range of several millimeters per year. Nonlinear, temporally variable VLM — driven by hydrocarbon extraction cycles, groundwater dynamics, and precipitation — can expand local RSLR projection uncertainty envelopes on the order of decimeters by 2050, depending on site-specific VLM trajectories. Critically, Govorcin et al. demonstrate that in parts of Los Angeles, combining local VLM with oceanic sea level rise produces 2050 projections that are more than double what regional tide-gauge or IPCC curves alone would indicate. The 0.4 m figure cited in the literature for VLM-driven projection uncertainty in some LA and San Diego locations represents the required sensitivity band for rEIR scenario analysis, not a single deterministic outcome.

A complementary dataset from Blackwell et al. (2020) — based on ALOS, Sentinel-1, and GNSS data and resolving VLM at approximately 100-meter pixel scale — explicitly documents subsidence rates up to −8.7 mm/yr along sections of the California coast and slower but significant rates on the order of −2 mm/yr in parts of Southern California. The Ballona/Playa del Rey area falls within the Southern California coastal zone studied by both teams. Neither dataset has been integrated into CDFW's flood modeling for the prior EIR or, to date, the rEIR.

The methodological standard established by this body of work is unambiguous: an adequate site-specific RSLR analysis requires site-specific VLM data at InSAR resolution. Regional averages applied without local geodetic adjustment are no longer consistent with the best available science.

Primary reference: Govorcin, M., et al. (2025). Variable vertical land motion and its impacts on sea level rise projections. *Science Advances.* https://www.science.org/doi/10.1126/sciadv.ads8163

Dataset: Blackwell et al. 100-meter VLM dataset (2007–2018). https://zenodo.org/records/11154177

3. Site-Specific VLM Drivers at BWER

The Ballona Wetlands Ecological Reserve sits at the intersection of three independent, overlapping mechanisms capable of producing nonlinear, difficult-to-predict VLM over the exact footprint where levee modification and channel reconfiguration are under consideration. Each mechanism is described below. Their significance lies not in any single driver in isolation, but in their compounding effect on a subsurface that is already responsive to pressure, moisture, and load changes.

3.1 Holocene Sediment Compaction

The BWER occupies the historic depocenter of the Ballona Creek alluvial and estuarine system. The site is underlain by Holocene-age deposits of high compressibility — organic-rich estuarine muds, alluvial silts, and sand-mud sequences that respond to changes in loading, drainage, and tidal regime. Historical modifications to the Ballona system — flood control channelization, agricultural drainage, fill placement, and the construction of Marina del Rey — altered the hydrological and load conditions under which these sediments are consolidating.

Compaction-driven subsidence in such settings is well-documented globally and in the California coastal literature. It is ongoing, independent of anthropogenic extraction, and is expected to persist throughout the 2050 and 2100 planning horizons relevant to the rEIR. Any proposed levee modification that alters drainage patterns, tidal prism, or sediment supply will interact with this ongoing compaction process in ways that must be quantified rather than assumed to be neutral.

3.2 Playa del Rey Natural Gas Storage Field

The Playa del Rey (PDR) oil and gas field has been in operation since the 1930s. SoCalGas converted it to a natural gas storage facility in 1955, and it has operated as a pressure-cycling storage reservoir ever since, with gas injected in summer and withdrawn in winter. The field's reservoir boundary extends toward the western portion of the BWER footprint.

The PDR field is a plausible and mechanistically coherent driver of localized VLM. Decades of oil and gas extraction prior to conversion to storage created permanent formation volume loss — a known precursor to compaction subsidence. Ongoing seasonal pressure cycling drives cyclical deformation of the overlying surface. The scientific literature on reservoir and aquifer compaction is clear that even low-millimeter-per-year rates, if sustained or episodically intensified over decadal timescales, materially alter relative sea level and flood risk.

SoCalGas has conducted satellite-based InSAR monitoring of the PDR field pursuant to a 2007 CPUC settlement agreement that specifically recognized the risk of subsidence associated with field operations. The monitoring record — to the extent it has been made publicly available — shows a dynamic, pressure-responsive subsurface. The 2011 interim report (RADARSAT-2) documented localized deformation of approximately 3–6 mm in the eastern reservoir boundary area. Subsequent 2012–2013 analyses (SoCalGas Interim Final Report) found both small uplift intervals (approximately 6–9 mm) and subsidence patches (approximately 6–12 mm) in different monitoring periods, with SoCalGas attributing a portion of the variance to soil moisture effects. This variability is itself technically significant: it confirms that the subsurface beneath and

adjacent to BWER is actively responding to pressure and moisture changes, which is precisely the condition associated with nonlinear, extraction-linked VLM in the Govorcin et al. (2025) dataset.

The public record for PDR subsidence monitoring appears to extend only through approximately 2013. The absence of publicly available monitoring data for the period 2013 to the present is a regulatory transparency concern that the rEIR must address. The CPUC monitoring obligation exists because the risk of subsidence was formally recognized; the data gap does not diminish that risk, it amplifies the uncertainty that must be bracketed in any adequate flood model.

For rEIR purposes, the PDR field cannot be treated as neutral with respect to VLM. Its contribution must be addressed through site-specific time-series geodetic analysis covering the full operational period, and the rEIR must demonstrate that the best available science — including the Govorcin et al. finding that nonlinear, extraction-linked VLM significantly increases projection uncertainty — has been applied.

3.3 Groundwater History

The Los Angeles coastal basin has experienced significant historical groundwater extraction. Govorcin et al. (2025) identify the Santa Ana aquifer system in the Los Angeles region as exhibiting temporal VLM variability of 3–5 mm/yr associated with groundwater dynamics, driven by interactions among extraction, recharge, and drought cycles. While the BWER area is not the primary locus of extraction, it sits within the regional groundwater system and may experience VLM correlated with basin-wide hydrological conditions — including variability that standard linear projections would not capture.

4. The rEIR Modeling Deficiency

The technical deficiency in the prior EIR — and the risk it poses to the rEIR if uncorrected — can be stated precisely: reliance on regional sea-level-rise projections without site-specific VLM adjustment produces a systematically underestimated flood surface elevation at BWER. The deficiency is not marginal. In a setting with multiple overlapping VLM drivers, the underestimation compounds across the planning horizon.

The structure of the required correction is set out in the table below. Each element is independently grounded in peer-reviewed science and is directly applicable to the rEIR process.

Element	Technical Basis and rEIR Requirement

A. Established Science	Relative sea level = eustatic rise + VLM. Failure to incorporate site-specific VLM produces systematic underestimation of RSLR. This is not disputed in the coastal engineering or geodesy literature.
B. Empirical Observation	NASA/JPL Sentinel-1 InSAR (2015–2023) and Blackwell et al. (2020) confirm spatially heterogeneous, temporally nonlinear VLM across the Los Angeles coastal zone at 90–100 m resolution. Regional averages do not capture site-scale variation. Both datasets are publicly available and must be applied.
C. Site Conditions	BWER is underlain by compressible Holocene alluvial and estuarine sediments, adjacent to a pressure-cycling gas storage reservoir with a CPUC-mandated subsidence monitoring history, and within a groundwater basin subject to historical extraction variability. These are precisely the conditions associated with nonlinear subsidence in the new datasets.
D. Modeling Requirement	Adequate flood risk modeling for the rEIR requires site-specific RSLR inputs derived from local InSAR/GNSS measurement, applied to evolve digital elevation model (DEM) ground surfaces through at least 2050. Holding DEMs fixed at current elevation while applying rising water levels is not consistent with best available science.
E. Scenario Requirement	The rEIR must present at minimum three VLM scenarios for each OPC sea level rise curve: (1) neutral/uplift, (2) median local subsidence reflecting documented regional rates, and (3) high subsidence reflecting combined estuarine compaction plus extraction-driven trends. The ~0.4 m VLM-driven uncertainty documented by Govorcin et al. for parts of Los Angeles defines the required sensitivity band.
F. Deficiency Claim	If the rEIR flood model applies regional SLR projections without site-specific VLM, it underestimates flood surface elevation, mischaracterizes infrastructure and habitat risk, fails to bracket uncertainty adequately, and does not reflect the best available science as required under CEQA.

5. Implications for the 68,000 cfs Standard and the No Project Alternative

Two specific analytical consequences flow from the VLM findings that have not been adequately addressed in the prior EIR and must be corrected in the rEIR. They are related but distinct, and each carries independent legal and technical weight.

5.1 The 68,000 cfs Standard Must Be Evaluated in Terms of Water Surface Elevation

The Chalfant ruling established 68,000 cfs as the Standard Project Flood design requirement for Ballona Creek levee modifications. This standard was developed in terms of discharge.

However, the flood protection that a levee actually provides is a function of water surface elevation and available freeboard — not discharge alone. These two framings produce the same result only if ground elevation is static.

In a subsiding basin, ground elevation is not static. As the land surface descends, the freeboard above a given water surface elevation decreases, even if the levee crest height remains unchanged. A levee designed to pass 68,000 cfs with adequate freeboard under current ground conditions will provide less freeboard — and potentially inadequate protection — as cumulative VLM lowers the surrounding land surface over the project's operational lifetime.

The rEIR must therefore evaluate compliance with the 68,000 cfs standard not only in terms of discharge capacity but in terms of water surface elevation and freeboard margin under dynamic VLM conditions projected through the design horizon. This is not a supplemental refinement; it is a prerequisite for demonstrating that the project will not impair flood control capacity under the USACE Section 408 review standard, which requires that modifications not increase flood risk to the surrounding community.

Where dynamic VLM analysis reveals that proposed levee configurations will not maintain adequate freeboard through the design horizon, the rEIR must evaluate engineered alternatives — including gated structures that can be adjusted as conditions change, and sediment augmentation strategies that can counteract compaction-driven marsh platform loss — rather than assuming that open-channel or breached-levee configurations will remain protective.

5.2 The No Project Alternative Requires Reassessment

The prior EIR characterized the No Project alternative as presenting greater long-term flood and habitat risk than the preferred restoration alternative, in part because sea level rise would progressively inundate remaining wetland habitats without the proposed tidal reconnection and levee modifications. That characterization was made without adequate VLM analysis. When realistic local VLM is incorporated, the comparison changes materially.

Opening additional tidal prism into a basin that is subsiding from multiple overlapping causes — sediment compaction, gas storage pressure cycling, and groundwater dynamics — accelerates the rate at which tidal exchange reaches infrastructure and habitats currently protected by existing flood control features. The relevant question is not only how much sea level will rise over the planning horizon, but how that rise interacts with a land surface that is itself descending. In a subsiding basin, these two processes compound rather than add linearly, and the combined trajectory can reach threshold elevations for habitat loss and infrastructure inundation sooner than either process alone would predict.

The Los Angeles Audubon Society's finding — that impacts from sea level rise on protected species and habitats may be less severe under the No Project alternative than under the preferred project — becomes materially more plausible once site-specific VLM is incorporated into the comparative analysis. This is not an argument against restoration in principle; it is an

argument that the risk calculus presented in the prior EIR was based on incomplete hydrology, and that the rEIR must present a corrected comparison using best available VLM science before any alternative can be declared preferable on flood risk grounds or certified as adequate under CEQA.

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6. Requirements for the Revised EIR

The following requirements flow directly from the technical findings presented above. Each is independently grounded in peer-reviewed science, is operationally specific, and is calibrated to what is necessary for the rEIR to constitute an adequate analysis under CEQA.

- Site-specific VLM quantification. The rEIR must apply InSAR-derived VLM rates at BWER-scale resolution, drawing on the Govorcin et al. (2025) Sentinel-1 dataset and the Blackwell et al. (2020) 100-meter dataset as minimum baselines. Both datasets are publicly available. VLM rates must be applied to evolve DEM ground elevations through at least 2050, and preferably through 2100, rather than holding elevations fixed.

- Explicit separation of VLM and eustatic components. The RSLR projection used in all flood modeling must state the VLM input and its geodetic source separately from the OPC eustatic projection. The two components must not be conflated in a single regional figure.

- Three-scenario VLM sensitivity analysis. For each OPC sea level rise curve, the rEIR must present results under: (1) a neutral or slight uplift scenario, (2) a median local subsidence scenario reflecting documented regional InSAR rates, and (3) a high subsidence scenario reflecting the combined effect of estuarine compaction, extraction-linked subsidence, and groundwater variability. The ~0.4 m uncertainty envelope documented by Govorcin et al. for parts of Los Angeles defines the outer bound of the required sensitivity range.

- Freeboard analysis under dynamic VLM. The 68,000 cfs design standard must be evaluated in terms of water surface elevation and freeboard margin under each VLM scenario through the design horizon, not discharge alone. Any proposed levee configuration must demonstrate that adequate freeboard is maintained under the median and high subsidence scenarios, not only under current ground conditions.

- PDR field monitoring gap. The rEIR must address the absence of publicly available subsidence monitoring data for the Playa del Rey storage field for the period 2013 to the present. CDFW should require SoCalGas to provide the complete InSAR monitoring record through the date of rEIR publication as a condition of adequate impact analysis. If

that record is unavailable, the rEIR must treat extraction-linked VLM at BWER as an unquantified uncertainty and apply conservative assumptions accordingly.

- Revised No Project alternative comparison. The comparative flood and habitat risk analysis for the No Project alternative must be regenerated using site-specific RSLR inputs incorporating local VLM. The prior EIR's characterization of No Project risk cannot stand as the basis for alternative selection given the demonstrated inadequacy of its hydrological inputs.

- Independent geodetic review. Given the litigation history, the magnitude of proposed levee modifications, and the significance of VLM to both Section 408 compliance and CEQA adequacy, independent geodetic review of the VLM inputs used in the rEIR is warranted before certification.

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7. Key References

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